Designs for Nationwide Randomized and Targeted Studies of the Occurrence of MTBE and Other Volatile Organic Compounds (VOCs) in Drinking Water Sources

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ABSTRACT

The American Water Works Association (AWWA) Research Foundation has funded a study to determine the national occurrence of methyl *tert*-butyl ether (MTBE) in drinking water sources. The study is being conducted by the Metropolitan Water District of Southern California (MWDSC), the U.S. Geological Survey (USGS), and the Oregon Graduate Institute (OGI). The initial phase of the study involves the design of two surveys, one randomized and one targeted, to gain a comprehensive assessment of the nationwide occurrence of MTBE in ground and surface water supplies.

DESIGN OF THE RANDOM SOURCE-WATER SURVEY

Objective

The objective of the random source-water survey is to provide representative information on the frequency of detection, concentration, and distribution of the gasoline additive MTBE, other ether oxygenates (hereafter termed "other oxygenates"), and VOCs in untreated, surface and ground waters that are sources for drinking water supplied by community water systems (CWSs) in the United States.

National Design Elements

Approximately 180,000 public water systems (PWSs) provide drinking water, at least some of the time, to more than 250 million people in the 50 States, the District of Columbia, Native American Lands, and the six U.S. Territories [1]; however, only about 50,000 of the PWSs are CWSs that supply water to the same population year-round. Although non-transient, non-community water systems (NTNCWSs), which include schools, factories, and hospitals, can contribute substantially to an individual's daily water intake, the population served by NTNCWSs (about 6 million) is relatively small.

For the national assessment of MTBE and other VOCs in drinking water, new data will be collected as part of two surveys of source waters. The first of these—the Random Source-Water Survey—will determine the frequency of detection and the range in concentrations of four oxygenates and 62 other VOCs (see Table 1) in drinking-water sources through a representative random sampling of 1,000 CWSs. A random design will allow information developed on the frequency and concentration of MTBE and other VOCs in drinking-water sources for the 1,000 randomly sampled CWSs to represent, in the aggregate, the overall population of CWSs.

Table 1. Volatile Organic Compound Analytes for Random Source-Water Survey

Analyte	MDL[a] (µg/L)	MRL[b] (µg/L)	USEPA MCL[c] (µg/L)	HA[d] (µg/L)	USEPA DWCCL[e] #
Ether Oxygenates					
tert-Amyl methyl ether	0.025	0.2			
Ethyl *tert*-butyl ether	0.034	0.2			
MTBE	0.039	0.2		20-40*	Yes
Diisopropyl ether	0.073	0.2			
VOCs on DWCCL#					
Bromobenzene	0.029	0.2			Yes
Bromomethane	0.084	0.2		10	Yes
1,1-Dichloroethane	0.036	0.2			Yes
1,3-Dichloropropane	0.029	0.2			Yes
2,2-Dichloropropane	0.056	0.2			Yes
1,1-Dichloropropene	0.060	0.2			Yes
cis-1,3-Dichloropropene	0.024	0.2			Yes
trans-1,3-Dichloropropene	0.026	0.2			Yes
Hexachlorobutadiene	0.057	0.2		1	Yes
4-Isopropyltoluene	0.037	0.2			Yes
Naphthalene	0.055	0.2		20	Yes
1,1,2,2-Tetrachloroethane	0.026	0.2			Yes
1,2,4-Trimethylbenzene	0.022	0.2			Yes
Other VOCs					
Acrylonitrile	0.098	0.2			
Benzene	0.029	0.2	5		
Bromochloromethane	0.036	0.2		10	
Bromodichloromethane	0.018	0.2	**		
Bromoform	0.022	0.2	**		
2-Butanone	0.645	2.0			
sec-Butylbenzene	0.044	0.2			
tert-Butylbenzene	0.037	0.2			
n-Butylbenzene	0.047	0.2			
Carbon tetrachloride	0.049	0.2	5		
Chlorobenzene	0.032	0.2	100	100	
Chloroethane	0.095	0.2			
Chloroform	0.024	0.2	**		
Chloromethane	0.105	0.2		3	
2-Chlorotoluene	0.033	0.2		100	
4-Chlorotoluene	0.030	0.2		100	
Dibromochloromethane	0.016	0.2	**	60	
1,2-Dibromoethane	0.029	0.2	0.05		
Dibromomethane	0.028	0.2			
1,2-Dichlorobenzene	0.037	0.2	600	600	
1,3-Dichlorobenzene	0.029	0.2		600	
1,4-Dichlorobenzene	0.033	0.2	75	75	

Table 1 (cont.)

Analyte	MDL (μg/L)	Proposed MRL (μg/L)	USEPA MCL (μg/L)	HA (μg/L)	USEPA DWCCL #
Dichlorodifluoromethane	0.121	0.2		1,000	
1,2-Dichloroethane	0.029	0.2	5		
1,1-Dichloroethene	0.082	0.2	7	7	
cis-1,2-Dichloroethene	0.024	0.2	70	70	
trans-1,2-Dichloroethene	0.040	0.2	100	100	
1,2-Dichloropropane	0.028	0.2	5		
Ethylbenzene	0.033	0.2	700	700	
1,1,1,2,2,2-Hexachloroethane	0.086	0.2		1,000	
Isopropylbenzene	0.040	0.2			
Methylene chloride	0.021	0.2	5		
n-Propylbenzene	0.043	0.2			
Styrene	0.026	0.2	600	100	
1,1,1,2-Tetrachloroethane	0.026	0.2		70	
Tetrachloroethene	0.049	0.2	5		
Toluene	0.025	0.2	1,000	1,000	
1,2,3-Trichlorobenzene	0.042	0.2			
1,2,4-Trichlorobenzene	0.042	0.2	70	70	
1,1,1-Trichloroethane	0.045	0.2	200	200	
1,1,2-Trichloroethane	0.014	0.2	5	3	
Trichloroethene	0.034	0.2	5		
Trichlorofluoromethane	0.096	0.2		2000	
1,2,3-Trichloropropane	0.027	0.2		40	
1,1,2-Trichloro-1,2,2-trifluoroethane	0.099	0.2			
1,3,5-Trimethylbenzene	0.026	0.2			
Vinyl chloride	0.082	0.2	2		
Vinyl Bromide	0.084	0.2			
m,p-Xylene	0.065	0.2	10,000	10,000	
o-Xylene	0.028	0.2	10,000	10,000	

[a]MDL = method detection limit. [b]MRL = minimum reporting level.

[c]USEPA MCL= U.S. Environmental Protection Agency maximum contaminant level.

[d]HA = health advisory. [e]DWCCL = USEPA Drinking-Water Candidate Contaminant List [2].

* Range for MTBE health advisory.

** Total for trihalomethanes (THMs) cannot exceed 100 μg/L.

? MDL or MRL not yet available. MWDSC's current VOC MDLs and MRLs will be reevaluated prior to initiation of the project.

The sample size was determined on the basis of statistical and logistical considerations. The results of the VOC analyses will have a binomial distribution because a compound is either detected or not detected, or does or does not exceed a specified concentration threshold such as a maximum contaminant level (MCL). The number of samples required to provide a specified confidence interval for the unknown probability (p) of a VOC being detected (or exceeding some concentration threshold) with an allowable error (d) of "±d" can be determined from the binomial distribution [3]. With 1,000 samples, p can be

determined to be within plus or minus 3.1 percent at the 95-percent confidence level. Previous USEPA national surveys of VOCs had similar or smaller sample size [4]. Also, estimates of the number of samples that could be processed monthly by MWDSC's Water Quality Laboratory, in addition to its normal regulatory sample load, were on the order of 60 to 100. Conducting the random source-water survey over a 15-month period will allow sample loads of about 40 to 80 samples per month with this design.

About 11 percent of the CWSs rely on surface-water sources, but they supplied nearly 168 million people or two-thirds of the population served by CWSs in 1998. Most CWSs (89 percent) are exclusively or primarily ground water-supplied, but they collectively served just one-third of the population or about 84 million people in 1998. If a sample of CWSs were based exclusively on their distribution by type of source water, 89 percent of the systems sampled would use ground water. However, this would strongly bias the results of the source-water survey toward small systems in rural parts of the country, where the frequency of VOC detection may be low. Conversely, if the design considered only population served, two-thirds of the sampled CWSs would be surface-water supplied, and the results of the survey might be similarly biased (lower VOC concentrations generally have been reported in surface waters than ground waters). A more balanced design for the random source-water survey would consequently use both factors—source of water and population served—as stratification factors.

Data on the number of CWSs and the population served by active CWSs were obtained from the USEPA's Safe Drinking Water Information System (SDWIS) on November 5, 1998. These data indicate that there were 54,305 active CWSs serving 251,659,380 people in the United States, U.S. Territories, and Native American Lands on that date. According to the SDWIS database, however, 7,345 systems purchase 100 percent of the water they distribute from other CWSs. Systems that purchase 100 percent of their water supplies do not have ground- or surface-water sources that may be sampled for this project. Therefore, the 7,345 purchased-water CWSs have been excluded from the count of systems, but not from population-served data, used to design the random source-water survey (Table 2).

The range in population served by CWSs has been subdivided into five CWS-size categories. Generally, they are the same categories that are used by the USEPA when presenting information on the occurrence of contaminants in drinking water [5], with one difference—the category that defines the largest CWSs includes all systems that serve 50,000 or more people rather than 100,000 or more people. This change was intended to include more of the larger systems in the random design. The five CWS-size categories used in the random source-water survey are the following:

- Very small (VSM)—25 to 500 people served
- Small (SM)—501 to 3,300 people served
- Medium (MED)—3,301 to 10,000 people served
- Large (LRG)—10,001 to 50,000 people served
- Very large (VLRG)—more than 50,000 people served

Table 2. Distribution of the Number of Self-Supplied CWSs and the Number of People Served by Source of Water and Size of System*

CWS Size Category	Ground Water		Surface Water	
	Number of Systems	Number of People Served	Number of Systems	Number of People Served
VSM	28,324	4,625,130	1,228	616,012
SM	9,775	14,178,037	1,562	5,739,217
MED	2,399	14,219,831	971	11,045,463
LRG	1,194	25,342,137	928	36,525,585
VLRG	182	25,696,338	397	113,671,630
Total	41,874	84,061,473	5,086	167,597,907

*Data from USEPA's SDWIS, November 5, 1998.

The design of the random source-water survey distributes the total number of samples (N=1,000) among 10 source-size categories based on the relative proportion of all self-supplied systems (A) and the percentage of the total population served (B) by CWSs within each category (Table 3). The percentage of the total number of CWSs within each source-size category and the percentage of the total population served by all CWSs within that particular source-size category are summed and divided by 2. The number of samples per category (n) is the product of the mean percentage (C) and the total sample population (N). The distribution of systems to be sampled is consequently weighted toward small ground-water systems reflecting the prevalence of these systems, but also includes nearly as many large surface-water systems—reflecting the large proportion of the population served by these systems. The overall distribution obtained by this design increases the number of systems to be included from the negatively skewed tails of the population distribution functions for each factor and better represents the actual distribution of CWSs than can be obtained by using either factor alone.

Table 3. Distribution of CWSs to be Sampled During Random Source Water Survey Based on Mean Percentage of Number of Systems and Number of People Served by Size Category and Source of Water

Source-size category	A. Percent of total number of systems	B. Percent of total number of people served	C. Mean percentage (A+B)/2	Number (n) of CWSs to be sampled by source and size
Ground Water (GW)				
GW-VSM	60.3	1.84	31.1	311
GW-SM	20.8	5.63	13.2	132
GW-MED	5.11	5.65	5.38	54
GW-LRG	2.54	10.1	6.32	63
GW-VLRG	0.39	10.2	5.30	53
All GW	**89.1**	**33.4**	**61.3**	**613**

Table 3 (cont.)

Source-size category	A. Percent of total number of systems	B. Percent of total number of people served	C. Mean percentage (A+B)/2	Number (n) of CWSs to be sampled by source and size
Surface Water (GW)				
SW-VSM	2.64	0.24	1.44	14
SW-SM	3.33	2.28	2.80	28
SW-MED	2.07	4.39	3.23	32
SW-LRG	1.98	14.5	8.24	83
SW-VLRG	0.85	45.2	23.0	230
All SW	**10.9**	**66.6**	**38.7**	**387**
TOTAL	100.0	100.0	100.0	1,000

The random source-water survey will sample 387 surface-water-supplied systems and 613 ground-water-supplied systems. Using the average population served by each CWS within the 10 source-size categories, a random source-water survey of 1,000 CWSs would provide information on VOC exposure through drinking water for an estimated 80 million people, or about 31 percent of the total population served by CWSs in November, 1998. Using source-water type alone in the design, only about 2 million people would have been included in the survey. When the random selection process has been completed, information specific to each participating CWS can be summarized to provide an actual determination of the total population served by the selected systems and the proportion of all CWS customers represented.

Allocation of Samples by State

In an extension of the overall design described above, a weighted random selection of CWSs was conducted based on the number of systems and population served within each of 52 geographic entities—the 50 States, Native American Lands, and the collective U.S. Territories. The weighted random selection was made from lists of CWSs in each of the 52 geographic entities to provide a more representative distribution of participating CWSs than might be obtained from a simple random selection from the total, national population of CWSs in each category. Similar to the overall design process, the average relative proportion of the number of CWSs and the percent of the population served within each source-size category was calculated for each state, Native American Lands, and the collective U.S. Territories. This average percent for each of the 52 geographic entities is multiplied by the total number of CWSs to be sampled from each category from the overall design (Table 3). For example, in California there are 1,963 ground water-supplied, very small CWSs that collectively supply 269,727 people. Consequently, California includes 6.9 percent of the 28,324 CWSs and 5.8 percent of the 4.6 million people served by CWSs in that category (see Table 2). Averaging these two values, California should contain 6.4 percent of the 311 ground water-supplied, very small CWSs to be sampled for the Random Source-Water Survey, or (with rounding) 20 randomly selected CWSs from this category. Table 4 lists the number of participating CWSs that will be sought from each geographic entity for each of the 10 source-size categories. Selections will be made from randomized lists of active, self-supplied, water utilities obtained from the SDWIS database on November 5, 1998, until the requisite number of systems are obtained within each source-size category for each state, Native American Lands, and U.S. Territories.

Table 4. Distribution of CWSs to be Sampled During Random Source Water Survey by Source-Size Category and by State

State or other entity	Source-Size Category										
	GW-VSM	GW-SM	GW-MED	GW-LRG	SW-VLRG	SW-VSM	SW-SM	SW-MED	SW-LRG	SW-VLRG	Total
AK	4	1	0	0	0	1	0	0	0	1	7
AL	0	2	2	1	0	0	0	1	3	5	14
AR	2	2	1	0	0	0	1	1	1	1	9
AZ	5	2	1	2	1	0	0	0	0	6	17
CA	20	5	3	7	11	2	2	2	5	30	87
CO	5	1	0	0	0	1	1	1	2	6	17
CT	5	1	0	0	0	0	0	0	2	5	13
DE	2	1	0	0	0	0	0	0	0	1	4
FL	13	6	3	7	17	0	0	0	1	3	50
GA	12	3	1	1	1	0	1	1	3	8	31
HI	0	1	0	0	1	0	0	0	0	0	2
IA	7	4	1	1	1	0	0	0	0	2	16
ID	5	1	1	1	0	1	0	0	0	1	10
IL	7	5	2	2	1	0	1	1	3	8	30
IN	4	4	2	2	1	0	0	1	1	4	19
KS	4	3	0	1	0	0	1	1	1	3	14
KY	1	0	0	0	0	0	1	2	5	2	11
LA	8	5	3	2	2	0	0	1	1	5	27
MA	2	1	2	3	1	0	0	1	4	8	22
MD	4	1	1	1	0	0	0	0	1	5	13
ME	2	1	0	0	0	0	1	0	1	0	5
MI	9	4	1	1	1	0	0	1	2	4	23
MN	6	4	1	3	0	0	0	0	1	2	17
MO	8	4	2	1	1	0	1	1	1	4	23
MS	5	9	3	2	0	0	0	0	0	0	19
MT	5	1	0	0	0	0	0	0	0	1	7
NC	16	3	1	1	0	0	1	2	4	7	35
ND	1	1	0	0	0	0	0	0	1	0	3
NE	5	2	1	1	0	0	0	0	0	1	10
NH	5	1	0	0	0	0	0	0	1	1	8
NJ	3	2	2	4	1	0	0	0	1	8	21
NM	5	1	1	1	1	0	0	0	0	0	9
NV	2	1	0	0	0	0	0	0	0	1	4
NY	15	4	1	3	4	1	2	2	4	16	52
OH	7	4	2	3	2	0	1	1	4	10	34
OK	3	2	1	1	0	1	2	2	2	4	18
OR	6	1	0	1	0	1	1	1	2	2	15
PA	14	5	2	1	0	1	1	2	6	15	47
RI	0	0	0	0	0	0	0	0	0	1	1
SC	4	1	1	0	0	0	0	0	2	3	11
SD	2	1	0	0	0	0	0	0	0	1	4
TN	1	1	1	1	1	0	1	2	4	4	16

Table 4 (Cont.)

State or other entity	Source-Size Category										
	GW-VSM	GW-SM	GW-MED	GW-LRG	SW-VLRG	SW-VSM	SW-SM	SW-MED	SW-LRG	SW-VLRG	Total
TX	24	14	6	3	3	1	2	2	5	17	77
UT	3	1	1	1	0	0	0	0	0	4	10
VA	11	2	0	0	0	0	1	1	2	6	23
VT	3	1	0	0	0	0	1	0	0	0	5
WA	17	4	1	2	1	1	1	0	1	2	30
WI	7	4	2	1	1	0	0	0	1	3	19
WV	2	1	0	0	0	0	2	1	1	1	8
WY	2	0	0	0	0	0	0	0	0	0	2
NA*	6	2	0	0	0	1	0	0	0	0	9
TE**	2	1	1	1	0	2	2	1	4	8	22
TOTAL	311	132	54	63	53	14	28	32	83	230	1000

*Native American Lands
**United States Territories

Lists of CWSs for each source-size category and geographic dominion where one or more participating CWSs are needed (from Table 4) were randomized using the uniform random distribution method in MS Excel. Random numbers between 0 and 1.0 were generated for each CWS and sorted from lowest to highest. Selection of participating utilities will take place by contacting each CWS in sequence to solicit their participation in the survey until the requisite number of systems is achieved.

Temporal Distribution of Samples

Because the random source-water survey will be implemented over a 15-month period, the temporal distribution of CWS sample collection also will be randomized to prevent any seasonal bias in the data. Sampling source waters at the randomly selected CWSs will be conducted from May 1999 through July 2000. Although the sampling will take place over a 64-week period, the number of samples collected weekly should provide for an even distribution over a 52-week calendar year. Accomplishing that distribution requires that about half the number of weekly samples collected during the central 40 weeks of the survey be collected during the initial and final 12 weeks. Consequently, 10 samples per week will be collected during weeks 1–12 and weeks 53–64, whereas 19 samples per week will be collected during weeks 13–52.

A random selection of which CWSs are to be sampled during any specific week over the 64-week duration of the random source-water survey is needed to prevent any regional bias in the temporal sample distribution. Generic identification of the 1,000 CWSs to be sampled allowed a pre-selection temporal randomization of the CWS sampling sequence. Information on the source-size category, state, and number of CWSs from Table 4 was combined to create a generic identifier for each of the planned 1,000 CWSs. For example, Table 4 indicates that there will be four ground-water-supplied, very small CWSs sampled from Alaska; therefore, four of the generic identifiers would be "GW_VSM.AK1," "GW_VSM.AK2," "GW_VSM.AK3," and "GW_VSM.AK4." Similar identifiers were created for the other 996 CWSs to be included in the random source-water survey, as indicated in Table 4. The generic identifiers serve as "place

holders" in the random temporal distribution design until actual selection of the participating CWSs is completed. The list of the 1,000 generic identifiers was randomized using the uniform random distribution method in MS Excel. Random numbers between 0 and 1.0 were generated for each CWS and sorted from lowest to highest. Generic identifiers were then apportioned among the 64-week sampling sequence according to the sorted random numbers and number of samples allocated to each week (either 10 or 19). Table 5 shows the results of this procedure for the first and last weeks of the random source-water survey sampling sequence, when 10 samples will be collected each week.

Table 5. Randomized Temporal Distribution of CWSs Sampled During the First and Last Weeks of the Random Source-Water Survey

Sample Sequence	Random Number	Sample Week	Generic CWS Identifier	State	Selected CWS's PWSID*
1	0.002807703	Week 1	GW_SM.IN1	IN	0INxxxxxxx
2	0.004974517	Week 1	GW_LRG.OH1	OH	0OHxxxxxxx
3	0.005157628	Week 1	GW_SM.MO1	MO	0MOxxxxxxx
4	0.005920591	Week 1	GW_VSM.WI1	WI	0WIxxxxxxx
5	0.008178961	Week 1	GW_VSM.GA1	GA	0GAxxxxxxx
6	0.008575701	Week 1	SW_VLRG.CA1	CA	0CAxxxxxxx
7	0.014191107	Week 1	SW_VSM.NA1	NA	0xxxxxxxx*
8	0.014221625	Week 1	GW_VLRG.FL1	FL	0FLxxxxxxx
9	0.014252144	Week 1	SW_VLRG.MO1	MO	0MOxxxxxxx
10	0.014496292	Week 1	GW_LRG.CA1	CA	0CAxxxxxxx
991	0.990447707	Week 64	GW_VLRG.CA11	CA	0CAxxxxxxx
992	0.991241188	Week 64	GW_LRG.MA3	MA	0MAxxxxxxx
993	0.992522965	Week 64	SW_VLRG.MI4	MI	0MIxxxxxxx
994	0.993255409	Week 64	GW_VSM.NA6	NA	0xxxxxxxx*
995	0.993774224	Week 64	SW_VLRG.CA30	CA	0CAxxxxxxx
996	0.994232002	Week 64	SW_LRG.TE4	TE	0XXxxxxxx*
997	0.995330668	Week 64	GW_VSM.MN6	MN	0MNxxxxxxx
998	0.997711112	Week 64	GW_SM.FL6	FL	0FLxxxxxxx
999	0.998168889	Week 64	GW_VSM.WA17	WA	0WAxxxxxxx
1000	0.998718223	Week 64	GW_VSM.VA11	VA	0VAxxxxxxx

*****PWSID = SDWIS Public Water System Identification Number: a 10-digit unique alphanumeric identifier for every regulated public water system; consists of zero plus a two-letter state or territory abbreviation (for Native American Lands, a two-digit federal region code follows the zero) plus a seven-digit number.

Table 6 includes information that can be used to evaluate how well the random temporal sample distribution allocates samples from various parts of the nation and its territories over a 12-month "calendar year." The 50 States, Native American Lands, and U.S Territories were assigned to eight "regions" and the total number of samples to be collected within each region during each calendar month (assuming that week 1 of the survey would be May 2-8, 1999, and week 64 would be July 16-22, 2000) was counted. For most regions, the month-to-month variability in the number of samples collected is small, and the coefficients of variation for all regions except "other" are less than 0.5 and mostly less than 0.3. The "other" region has the fewest samples (40), but it also includes states that are not in similar geographic or climatic regions (Alaska, Hawaii, U.S. Territories, and Native American Lands).

Table 6. Temporal Distribution of CWSs to be Sampled During the Random Source-Water Survey Over a 12-Month Calendar Year in Eight Regions of the Nation

Region*	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Northeast & Mid-Atlantic	15	21	22	8	21	23	15	17	22	13	16	21	214
Southeast	10	11	20	13	15	8	13	11	18	11	11	16	157
Ohio Valley	12	17	7	10	13	7	10	10	11	12	8	8	125
Upper Midwest	6	7	7	12	8	9	17	6	6	9	9	10	106
South Central	11	11	11	14	10	16	19	9	13	7	10	19	150
Southwest	13	5	17	13	7	11	12	12	16	11	15	12	144
Northwest	3	3	7	5	4	4	4	8	6	7	7	6	64
Other	6	1	4	5	2	2	5	3	3	6	0	3	40
Total	76	76	95	80	80	80	95	76	95	76	76	95	1000

*Northeast & Mid-Atlantic: ME, NH, VT, MA, RI, CT, NY, NJ, PA, DE, MD, & VA
Southeast: FL, GA, AL, TN, NC, & SC
Ohio Valley: KY, WV, OH, IN, IL, & MI
Upper Midwest: WI, MN, ND, SD, NE, KS, MO, & IA
South Central: MS, LA, TX, OK, & AR
Southwest: CA, NV, AZ, NM, UT, & CO
Northwest: WA, OR, ID, MT, & WY
Other: AK, HI, NA, & TE

CWSs will be contacted in the sequence determined from the random selection process and asked to participate in the random source-water survey. As CWSs are contacted and agree to participate, the actual SDWIS PWSID for the CWSs will populate the sixth column of Table 5. In this way, the actual dates that the participating systems will collect and submit their source-water samples will be identified and communicated to the participants, and the laboratory can monitor sample flow and plan for sample workload.

Ancillary Information Collection

Ancillary information will be needed to allow for explanatory analysis of possible relations between the occurrence and distribution of MTBE or other VOCs in source-water samples collected for the Random Source-Water Survey and various natural or man-made factors. The information to be sought will include: location (latitude and longitude) of the sources sampled (well head or intakes); actual population served by the source; source characteristics (e.g., well depth, yield, aquifer type, surface-water type and size, intake specifics, and previous water-quality problems); MTBE and other fuel-oxygenate use areas; land use; population density; and known or potential VOC point-source locations (Toxic Release Inventory sites, leaking underground storage tanks, RCRA and CERCLA sites) in the vicinity of sampled CWS sources. This information will be obtained from available databases or collected directly from participating CWSs.

National geospatial data on land use, population density, and point-source locations are available and will be utilized to provide a consistent coverage for all participating CWSs. Information on MTBE or other fuel-oxygenate use will be compiled from USEPA documentation and industry surveys. But information on the precise locations of CWS sources is often missing from the SDWIS database and will need to be collected from the participating utilities.

A short questionnaire will be filled out during the initial telephone interview with CWS staff when they have agreed to participate in the random source-water survey. The phone-in questionnaire will be used to verify basic information obtained from the SDWIS database for the selected utility, ascertain additional information on the source water to be sampled, and identify the persons and the means for further contact.

A written (mail-in) questionnaire will be included with the sampling supplies sent to participating CWSs to collect ancillary information about the source water, intake location, filtration and treatment, distribution area, actual population served, and quantity of water delivered by suppliers. The questionnaire also will solicit information specific to ground-water sources (e.g., well characteristics, aquifer type, and vulnerability) or surface-water sources (watershed protection, recreational motorcraft use). In addition, latitude and longitude information will be collected from each utility for each sampled source (intake or wellhead). If latitude and longitude are not available, the utilities will be asked to identify the locations of sources (wellhead or intake) on a topographic map, from which the USGS will determine the latitude and longitude. The latitude and longitude will be entered into a geographical information system (GIS).

The utilities also will be asked whether the sites are located in air quality attainment or non-attainment areas. This ancillary information will be used to further explain the frequency and concentration of MTBE and other VOCs observed in source waters.

TARGETED SURVEY DESIGN

Objective

The primary objective of the targeted source-water survey is to provide an improved understanding of the frequency of detection, concentration, and temporal variability of MTBE, other ether oxygenates, their degradation by-products, and other VOCs in untreated source waters used by large CWSs in high MTBE use areas. Source waters selected for sampling will be those known or suspected to be more susceptible to contamination.

Background

The use of special blends of gasoline containing oxygenates is mandated under the 1990 Clean Air Act Amendments to reduce ozone and carbon monoxide levels in non-attainment areas. Much of the use of MTBE is located in reformulated gasoline (RFG) designated areas. Approximately 80 percent of RFG uses MTBE to achieve the minimum oxygen content of gasoline. In contrast, ethanol is the most frequently used in oxygenated gasoline (OXY) designated areas.

Select reservoirs, rivers, and aquifers will be sampled and about 480 VOC samples will be analyzed as part of the targeted sampling. About half of these samples will also be analyzed for oxygenate degradation by-products. This component of the project will focus additional sampling on selected CWSs that are located in areas of the United States where MTBE is used in RFG and OXY gasolines, and where MTBE is known or suspected to occur in sources of drinking water. The high content of MTBE in RFG (10-11 percent v/v) and OXY gasolines (15 percent v/v) has the potential to contaminate source waters.

Revised Schedule

The targeted source-water survey was scheduled to begin in November 1999 and last for about a year, with the study's design completed in the spring and summer of 1999. However, it is desirable to start some of the targeted sampling in the summer of 1999. Because the sampling protocol in the targeted survey is more complex than the random survey, USGS field staff will be collecting most of the samples in the targeted survey. USGS efforts in sample collection is an in-kind contribution to the AWWA Research Foundation project and starting the targeted sampling earlier allows the sampling to be done over approximately 18 months (July 1999 to October 2000) and spreads the field cost of sampling over two USGS fiscal years.

Study Design

The targeted source-water survey is designed based on factors that are known or appear to be related to frequent detection of MTBE and other VOCs. CWSs located in hydrologic, climatic, and demographic settings that are known or thought to be most vulnerable to MTBE contamination will be selected. For example, CWSs may be selected for sampling based on some or all of the following factors:

- Highly urbanized, high population density settings, where reformulated and oxygenated gasolines are required. This includes determination of air quality non-attainment areas where oxygenated fuels are used.
- Reservoirs and/or large rivers where motorized watercraft are allowed and gasoline containing MTBE is used.
- Streams and rivers that have deep, slow-moving, poorly mixed reaches up-gradient of CWS intakes, or during baseflow periods or other periods with little runoff and low dilution of transported VOCs.
- Ground water in urban areas where MTBE is used in gasoline; high precipitation and high recharge rates may rapidly transmit VOCs from the atmosphere or urban runoff to shallow ground water.
- Ground water, rivers, or streams serving as source waters to CWSs known to contain MTBE and other VOCs based on previously completed or on-going studies.

Approximately 480 samples will be collected from CWSs located in 30 cities and metropolitan areas and analyzed for MTBE, other ether oxygenates, their degradation by-products, and other VOCs. The distribution of targeted sampling by type of drinking-water source is shown in Table 7. However, plans for targeted sampling contain sufficient flexibility to redirect sampling if new data or retrospective information identify factors that merit further investigation.

Table 7

Targeted Source Water	Number of Source Waters	Sampling Frequency	Total Number of Samples
Ground water	80	Biannually	160
Reservoirs and lakes	40	Quarterly	160
Rivers and streams	20	8 per year	160
Total			480

A total of 30 metropolitan areas will be selected based on high MTBE use in gasoline and known or suspected MTBE contamination in drinking-water supplies. Information on aquifer vulnerability and local knowledge of MTBE occurrence or possible occurrence in drinking-water sources within each of these 30 cities and metropolitan areas will be obtained from discussions with local water agencies. From these discussions, CWSs will be selected and asked to participate. For those that agree to participate, the same ancillary information will be collected as was collected for the random design. The CWS may utilize one or all three of the source categories listed in Table 7. Thus, it is possible for samples to be collected from one, two, or three source categories per CWS per metropolitan area.

Considering the need to start some of the targeted sampling in summer of 1999, as well as to maintain an element of flexibility in the design to redirect sampling as new data emerge, the targeted source-water survey will be completed in two independent stages. Stage one focuses on CWSs located in metropolitan areas greater than about 250,000 population that use MTBE in RFG. Much of the MTBE use is located in RFG designated areas, and approximately 80 percent of RFG uses MTBE to achieve the minimum oxygen content of gasoline.

Recent USGS findings for shallow groundwater ($\leq$ about 200 ft well depth) indicate that the use of MTBE in gasoline in RFG and OXY areas increases the probability of detecting MTBE in ground water by a factor of 4 to 6. The USGS also estimates that approximately 20 million of the 50 million people who obtain drinking water from ground water in RFG or OXY areas use a water supply that is considered vulnerable to contamination by MTBE, other ether oxygenates, and other VOCs [6]. The vulnerability of aquifers to MTBE contamination appears to be mostly related to MTBE use, population density, and the presence of industry, commerce, and gasoline stations in the vicinity of sampled wells. Hydrogeologic factors such as well depth, ground-water level, and the presence of roads seem to be less important.

Data to populate stage 2 of the targeted source-water design will be obtained from recently completed or ongoing activities. These include, in part, the random source-water survey of this project, a 12-state northeast drinking-water retrospective, recent reports completed by the states of Maine and California, and other ancillary information as it becomes available.

Stage 1: CWSs in Large Metropolitan Areas That Use MTBE RFG

As indicated above, stage 1 focuses on CWSs located in metropolitan areas greater than 250,000 population that use MTBE in RFG. As such, the first step of stage 1 is to identify large cities that extensively use MTBE in gasoline. A subsequent step would then be to identify CWSs to sample within these metropolitan areas.

A total of 139 of the nation's largest cities and metropolitan areas were identified from 1992 census data projections. Twenty-seven of the 139 cities were determined to be required to use RFG or "opted-in" to the RFG program [7]. Thirteen of the 139 cities and metropolitan areas were determined to be in OXY gasoline areas. The majority of these latter cities use ethanol as the primary oxygenate in gasoline [8].

The Motor Gas Survey, which provides chemical analyses of gasoline collected from 111 select metropolitan locations around the nation, has included ether analyses since about 1991 by an independent firm (TRW Systems and Information Technology Group) based in Bartlesville, Oklahoma. Data from this survey collected during 1996 and 1997, the most recent data available, were examined and compared to all 139 cities. Generally, when MTBE was detected in gasoline, concentrations were either less than 1 percent v/v or approximately 10 percent v/v. As might be expected, cities using RFG had the highest MTBE concentrations in gasoline. Lower concentrations of MTBE may be caused by its use to enhance the octane of gasoline.

Based on review of population density, MTBE use in gasoline (i.e., RFG/OXY areas), and data obtained from actual gasoline analyses, nearly half (14) of the overall targeted source-water survey cities and metropolitan areas were selected to be included in stage 1. Cities with populations greater than 250,000 with MTBE concentrations in gasoline equal to or greater than 10 percent v/v as indicated from the Motor Gas Survey were chosen to be included in stage 1 (Table 8). All 14 cities are located in RFG areas (Figure 1).

Table 8. Listing of cities and metropolitan areas where MTBE is extensively used for inclusion in stage 1

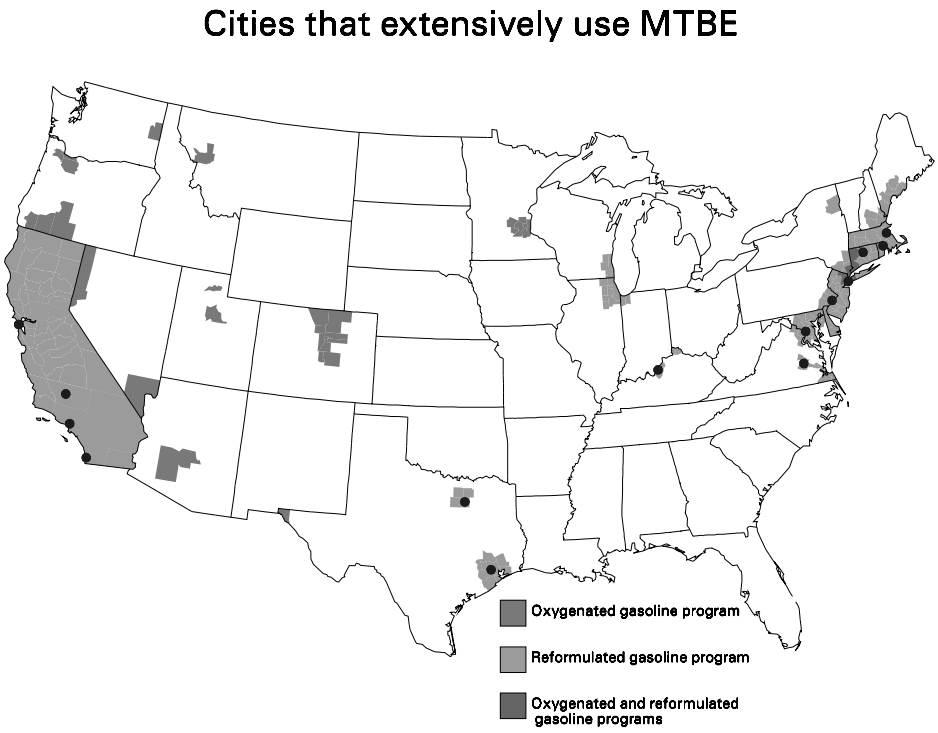
Number	City/Metropolitan Area
1	Bakersfield, CA (MSA[a])
2	Boston, MA (NECMA[b])
3	Dallas-Fort Worth, TX (CMSA[c])
4	Hartford, CT MSA (NECMA)
5	Houston-Galveston-Brazoria, TX (CMSA)
6	Los Angeles-Riverside-Orange County, CA(CMSA)
7	Louisville, KY-IN (MSA)
8	New York-Northern New Jersey-Long Island, NY-NJ-CT-PA (CMSA)
9	Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD (CMSA)
10	Providence-Fall River-Warwick, RI-MA (NECMA)
11	Richmond-Petersburg, VA (MSA)
12	San Diego, CA (MSA)
13	San Francisco-Oakland-San Jose, CA (CMSA)
14	Washington-Baltimore, DC-MD-VA-WV (CMSA)

[a]MSA = Metropolitan Statistical Area

[b]NECMA = New England County Metropolitan Area

[c]CMSA = Consolidated Metropolitan Statistical Area

Figure 1


Cities that extensively use MTBE
Oxygenated gasoline program
Reformulated gasoline program
Oxygenated and reformulated gasoline programs

Stage 1: CWS Selection Process

Data on CWSs and the population served by active CWSs were obtained from the USEPA's SDWIS. The targeted design focuses on large CWSs, however, Table 9 shows the distribution of all sizes of CWSs located in each of the 14 cities and metropolitan areas included in stage 1. These data indicate that there are a total of 5,922 CWSs serving 68,284,796 people in these 14 areas. When considering only those CWSs serving greater than 50,000 people, about 2.6 percent of all CWSs located in these 14 cities and metropolitan areas distribute water to over 75 percent of the population served. Four hundred fifty-five systems purchase all or some of the water they distribute from other CWSs. For this reason, these systems are excluded from sampling for the targeted source-water survey, but data are presented for comparative purposes.

Stage 1 identifies nearly half (14/30) of the total metropolitan areas to be included in the overall targeted source-water survey. For each of these 14 cities and metropolitan areas, Table 10 lists the recommended number of CWSs and sources to sample, not only to distribute samples evenly among the 14 cities but also to maintain an adequate number of samples for the overall targeted survey (Table 7).

CWSs will be selected based on the following criteria: (1) MTBE is known to occur in the source water based on recently completed or ongoing studies; (2) verbal communication from local, state, or other federal agency personnel indicating the presence or likelihood of MTBE in the source water; and (3) population served. It is not often that there is direct evidence of MTBE occurring in the source water in these 14 cities and metropolitan areas. Some exceptions include data from the 1997 interagency report [9], the state of California report [10], and also preliminary data from the 12 state northeast drinking-water retrospective [11]. Based on review of available information, Table 11 lists the candidate CWSs to be included in stage 1. Additional CWSs may be added to this list as discussions with local, state, or other federal agency personnel commence and recommended CWSs are confirmed.

The CWSs will be contacted by telephone to solicit participation. A phone survey database has been developed for the targeted survey. The potential participant will be told about the project and asked to participate. Upon acceptance to participate, questions will be asked to ascertain the source water sites for sampling. These data will be entered directly into the database. The date of the first sampling will be established and the participant will be also be told about the sampling frequency. The USGS field staff will conduct the sampling and will confirm the sampling date with the participant. In certain instances, the CWS may be asked to assist with the sampling.

A follow-up questionnaire will be sent to each participant to gather further ancillary information about the system and source waters. The CWS will be asked to complete the questionnaire and mail back to MWDSC. A self addressed/stamped return envelope will be provided for their convenience.

Table 9. Number of utilities by source-water type and population served for the 14 cities and metropolitan areas

City and Metro-politan Areas	Ground Water & Surface Water		Surface Water		Ground Water		Purchased Water	
	No. of CWS	Population Served	No. of CWS	Population Served	No. of CWS	Population Served	No. of CWS	Population Served
Bakers-field	5	36,450	3	12,403	217	325,837	7	216,390
Boston	42	1,179592	27	2,462,502	458	967,380	51	965,065
Dallas	6	117,485	30	1,363,816	436	233,660	51	1,923,773
Hartford	9	294,302	5	398,869	173	138,069	4	25,959
Houston	4	1,638,067	6	10,848	960	1,592,456	31	597,266
Los Angeles	30	5,493,638	21	809,704	628	6,988,545	18	1,898,098
Louisville	1	35,905	7	797,216	22	122,983	2	11,956
New York	21	292,600	39	7,011,073	768	3,715,133	165	5,373,628
Philadel-phia	7	162,590	16	2,071,270	373	737,199	90	2,637,555
Provi-dence	2	158,000	3	333,538	49	106,205	3	101,726
Richmond	3	122,650	5	259,931	122	55,051	2	150,268
San Diego	7	1,849,952	2	25,340	71	302,791	1	500,511
San Francisco	31	1,838,781	46	1,891,707	324	2,602,612	14	500,511
Washing-ton D.C.	12	145,569	30	3,662,626	446	399,651	16	1,102,605
Totals	180	13,365,581	240	21,110,843	5,047	18,287,572	455	15,520,800

Table 10. Recommended distribution of CWSs and number of sources to be sampled in the 14 cities and metropolitan areas selected for stage 1

City	Number of Aquifers, Springs, or Well Fields	Number of River/Stream Sources*	Number of Reservoir/Lake Sources
Bakersfield	2	1	1
Boston	2	1	1
Dallas	2	1	1
Hartford	2	1	1
Houston	2	1	1
Los Angeles	4	1	2
Louisville	2	1	1
New York	4	1	2
Philadelphia	4	1	2
Providence	2	1	1
Richmond	2	1	1
San Diego	2	1	1
San Francisco	4	1	2
Washington D.C.	4	1	2
Totals	38	9	19

* The total number of rivers/stream sources to target for the project is 20. In order to maintain this distribution, nine river/stream sources are targeted for stage 1, which will come from a subset of these cities and metropolitan areas, yet to be determined.

Table 11. Candidate community water systems to be contacted for stage 1 of the targeted source-water survey by city or metropolitan area

PWSID	CWS	Pop. Served	Source Type
Bakersfield Area			
CA1510031	BAKERSFIELD, CITY OF	60,720	only ground water
CA1510017	INDIAN WELLS VALLEY W.D.	32,630	only ground water
CA1510005	DELANO, CITY OF	31,235	only ground water
CA1510006	EAST NILES CSD	21,500	both ground and surface water
CA1510015	OILDALE MWC	20,000	only ground water
Boston Area			
MA6000000	MWRA	1,654,076	only surface water
MA2348000	WORCESTER DPW, WATER SUPPLY DIVISION	170,000	both ground and surface water
MA3160000	LOWELL WATER DEPARTMENT	135,000	both ground and surface water
MA4044000	BROCKTON WATER DEPARTMENT	105,000	both ground and surface water
MA4201000	NEW BEDFORD WATER DEPARTMENT	105,000	only surface water
MA4095000	FALL RIVER WATER DEPARTMENT	98,000	only surface water
Dallas/Ft. Worth Area			
TX2200012	FT WORTH, CITY OF	900,000	only surface water
TX2200001	ARLINGTON, CITY OF	290,000	only surface water
TX0610002	DENTON, CITY OF	70,600	both ground and surface water
TX0700008	WAXAHACHIE, CITY OF	23,946	only surface water
TX1160004	GREENVILLE, CITY OF	23,071	only surface water
Hartford Area			
CT1310011	SOUTHINGTON WATER DEPT	35,256	both ground and surface water
CT0640011	METROPOLITAN DISTRICT COMMISS.	391,250	only surface water
CT0890011	NEW BRITAIN WATER DEPT	90,677	both ground and surface water
CT0473011	CTWC, NORTHERN REG, WESTERN SYSTEM	62,000	both ground and surface water
CT0170011	BRISTOL WATER DEPT	52,328	both ground and surface water
CT0330011	CROMWELL FIRE DISTRICT	9,875	only ground water

Table 11 (cont.)

PWSID	CWS	Pop. Served	Source Type
CT0770021	MANCHESTER WATER DEPT	702	both ground and surface water
Houston Area			
TX1010118	CROSBY MUNICIPAL UTILITY DISTRICT	3,042	both ground and surface water
TX1010013	HOUSTON, CITY OF-PUBLIC WORKS DEPT	1,608,000	both ground and surface water
TX1011591	HOUSTON-GREENSPOINT	72,027	only ground water
TX1700197	SAN JACINTO RVR AUTH - WOODLAND	47,989	only ground water
TX1010348	HOUSTON CITY OF-UD NO 5	45,951	only ground water
Los Angeles Area			
CA1910067	LOS ANGELES-CITY, DEPT. OF WATER & POWER	3,600,000	both ground and surface water
CA1910048	CASTAIC LAKE WATER AGENCY	158,000	only surface water
CA3610006	WATER FACILITIES AUTHORITY-JPA	338,660	only surface water
CA3310009	EASTERN MWD	253,705	only ground water
CA3310001	COACHELLA VWD: COVE COMMUNITY	192,565	only ground water
Louisville Area			
KY0560258	LOUISVILLE WATER COMPANY	769,899	only surface water
IN5210005	JEFFERSONVILLE-INDIANA CITIES WATER	39,841	only ground water
KY0930333	OLDHAM CO WATER DISTRICT	13,860	only ground water
IN5222005	NEW ALBANY-INDIANA CITIES WATER	35,905	both ground and surface water
IN5272002	STUCKER FORK WATER UTILITIES	11,110	only surface water
New York Area			
NY7003493	NEW YORK CITY - AQUEDUCT SYSTEM	6,552,718	only surface water
NY2902835	LONG ISLAND WATER CORPORATION	230,830	only ground water
NJ1352005	NJ WATER SUPPLY AUTH MAN	35,589	only surface water
NY5110526	SUFFOLK COUNTY WATER AUTHORITY	941,000	only ground water
NY7011735	JAMAICA WATER SUPPLY COMPANY	518,000	only ground water

Table 11 (cont.)

PWSID	CWS	Pop. Served	Source Type
Philadelphia Area			
PA1510001	PHILADELPHIA WATER DEPARTMENT	1,755,000	only surface water
PA1230004	CHESTER WATER AUTHORITY	113,298	only surface water
NJ0119002	NJ AMERICAN W CO ATLANTIC	67,143	only ground water
PA1460046	PA AMERICAN WATER COMPANY	83,200	only surface water
DE0000634	NEW CASTLE WATER DEPT.	6,000	only ground water
Providence Area			
RI1592024	PROVIDENCE-CITY OF	286,923	only surface water
RI1592021	PAWTUCKET-CITY OF	108,000	both ground and surface water
RI1647515	BRISTOL COUNTY WATER AUTHORITY	50,000	both ground and surface water
RI1559518	WOONSOCKET WATER DEPARTMENT	46,000	only surface water
RI1559512	WESTERLY WATER DEPARTMENT	29,605	only ground water
Richmond Area			
VA4760100	CITY OF RICHMOND WTP	209,000	only surface water
VA3740600	CITY OF PORTSMOUTH	120,000	both ground and surface water
VA3670800	VIRGINIA-AMERICAN WATER CO	40,331	only surface water
VA4085398	LAKERIDGE INDUSTRIAL PARK	19,537	only ground water
VA4085840	ASHLAND WATER TREATMENT PLANT	5,100	only surface water
San Diego Area			
CA3710020	SAN DIEGO - CITY OF	1,177,400	both ground and surface water
CA3710010	HELIX WD	231,363	both ground and surface water
CA3710025	SWEETWATER AUTHORITY	160,400	both ground and surface water
CA3710014	OCEANSIDE - CITY OF	142,000	only ground water
CA3710006	ESCONDIDO - CITY OF	110,000	both ground and surface water

Table 11 (cont.)

PWSID	CWS	Pop. Served	Source Type
San Francisco Area			
CA4910011	SEBASTOPOL, CITY OF	7,744	only ground water
CA3810700	PRESIDIO OF SAN FRANCISCO	1,230	both ground and surface water
CA0110005	EAST BAY MUD	1,300,000	only surface water
CA4310011	SAN JOSE WATER COMPANY	928,000	only ground water
CA3810001	SF PUBLIC UTILITIES COMMISSION	750,000	both ground and surface water
Washington DC Area			
MD0300002	BALTIMORE, CITY OF	1,600,000	only surface water
VA6059501	FAIRFAX CO WTR AUTH JJCORBALIS	150,000	only surface water
WV3300212	CITY OF MARTINSBURG	13,030	only ground water
MD0150005	WASHINGTON SUBURBAN SAN COMM	1,500,000	only surface water
VA6177300	NI RIVER WTP	34,000	only surface water

Stage 2: CWSs With Known MTBE Contaminated Source Water

The second phase of the targeted source-water survey provides the aforementioned flexibility to the design and completes the scheduled sampling, as outlined in Table 7. Stage 2 sampling would start in approximately November, 1999 and builds, in part, upon knowledge gained from the results of the random survey. That is, CWSs that are found to contain elevated levels (>5 µg/L; taste and odor benchmark concentration) of MTBE in the random survey may warrant inclusion in the targeted survey to expand sampling of these source waters. In addition, knowledge gained from the 12-state northeast drinking-water retrospective, recent reports completed by the states of Maine and California, and other ancillary information as it becomes available will be used to select CWSs to include in the targeted source-water survey.

The project team is aware that some states which are not located in RFG or OXY gasoline areas have a very high frequency of detection of MTBE in ground water at regulated gasoline release sites. Discussions with select state underground storage tank (UST) program and drinking-water officials will be pursued in order to better understand the risk of MTBE releases to source waters in these states. These discussions may also lead to aquifers, reservoirs, or rivers that warrant sampling in the targeted source-water survey.

Sampling and Analysis

Insofar as possible, samples will be collected by experienced USGS field personnel. However, water utility staff may collect some samples in areas far removed from USGS field offices. Ground-water samples will be collected from water-supply wells as described by Koterba et al. [12]. Approximately 30 percent of the overall number of samples (480) will be quality-control samples; 20 percent blanks, 10 percent duplicates. That is, about 96 blank (0.2×480) and 48 duplicate (0.1×480) samples will be collected. Ground-water quality-control samples will include field blanks at approximately 70 percent of the ground water sites. Surface-water samples will be collected within 5 ft of the surface using a VOC hand-sampler as described by Shelton [13]. Surface-water quality-control samples, primarily equipment blanks, will also be collected as described by Shelton [13]. To the extent possible, surface-water equipment blanks will be collected at 70 percent of the sites. Duplicate samples will be collected when VOCs are known to occur based on previous sampling at the respective site. To the extent possible, duplicate samples will be spread evenly among ground-water, lakes/reservoirs, and stream/river sites. All of the samples collected for the targeted source-water survey will be analyzed using the same analytical schedule as was used for the random survey, which analyzes 67 VOCs including MTBE and other ether oxygenates. About half (240) of the targeted samples will also be analyzed for oxygenate degradation by-products. An analytical method has been developed by the OGI for this purpose, which gives rapid and sensitive detection of *tertiary*-butyl alcohol (TBA) and other likely products of MTBE degradation (such as *tertiary*-butyl formate (TBF), methyl acetate, isopropanol, and acetone), as well as MTBE itself [14]. Samples will be analyzed for oxygenate degradation by-products when MTBE or other oxygenates are known or highly likely to be present in the sample. This will be accomplished when samples previously analyzed as part of stage 1 or stage 2 of this design indicate the presence of fuel oxygenates.

REFERENCES

1. USEPA. Community Water Survey: Vol. 1, Overview. EPA 815-R-97-001a. USEPA Office of Water: Washington, D.C. (1997), 34 pp.
2. USEPA. Announcement of the Drinking Water Contaminant Candidate List; Notice. *Fed. Reg.*, Part 3 (March 2, 1998).
3. IMAN, R.L., & CONOVER, W.J. A Modern Approach to Statistics. Wiley: New York (1983).
4. WESTRICK, J.J. National Surveys of Volatile Organic Compounds in Ground and Surface Waters. In Ram, N.M.; Christman, R.F.; & Cantor, K.P., *Significance and Treatment of Volatile Organic Compounds in Water Supplies*. Lewis Publishers: Chelsea, Mich. (1990), pp. 103-125.
5. USEPA. Technical and Economic Capacity of States and Public Water Systems to Implement Drinking Water Regulations: Report to Congress. EPA 810-R-93-001 (G-134). ERIC Clearinghouse for Science, Mathematics, and Environmental Education: Columbus, Ohio (Sept. 1993), 127 pp. (with appendices).

6. SQUILLACE, P.J. Written personal communication. U.S. Geological Survey: Rapid City, S.D. (1999).
7. USEPA. List of Reformulated Gasoline Program Areas. Web page. USEPA Office of Mobile Sources: Washington, D.C. (April 5, 1999). [http://www.epa.gov/oms/rfgovea.htm]
8. USEPA. Winter Oxygenated Fuels Program. "Fuels" web page. USEPA Office of Mobile Sources: Washington, D.C. (June 16, 1999). [http://www.epa.gov/oms/fuels.htm]
9. ZOGORSKI, J.S.; BAER, A.L.; BAUMAN, B.M.; CONRAD, D.L.; DREW, R.T.; KORTE, N.E.; LAPHAM, W.W.; MORDUCHOWITZ, A.; PANKOW, J.F.; & WASHINGTON, E.R. Fuel Oxygenates and Water Quality. In *Interagency Assessment of Oxygenated Fuels* (Chapter 2). Office of Science and Technology Policy, The Executive Office of the President: Washington, D.C. (1997), pp. 2-1 to 2-80 (with appendices).
10. KELLER, A., FROINES, J., KOSHLAND, C., REUTER, J., SUFFET, I., & LAST, J. *Health and Environmental Assessment of MTBE; Summary and Recommendations.* University of California: Davis, Calif. (Nov. 1998), Vol. 1, p. 64.
11. GRADY, S.J., & CASEY, G.D. *A Plan for Assessing the Occurrence and Distribution of Methyl* tert*-Butyl Ether and Other Volatile Organic Compounds in Drinking Water and Ambient Ground Water in the Northeast and Mid-Atlantic Regions of the United States*. Open-File Report 99-207. U.S. Geological Survey: Reston, Va. (1999), 36 pp.
12. KOTERBA, M.T., WILDE, F.D., & LAPHAM, W.M. *Ground-Water Data-Collection Protocols and Procedures for the National Water-Quality Assessment Program—Collection and Documentation of Water-Quality Samples and Related Data*. Open-File Report 95-399. U.S. Geological Survey: Reston, Va. (1995), 113 pp.
13. SHELTON, L.R. *Field Guide for Collecting Samples for Analysis of Volatile Organic Compounds in Stream Water for the National Water Quality Assessment Program*. Open-File Report 97-401. U.S. Geological Survey: Reston, Va. (1997), 14 pp.
14. CHURCH, C.D., ISABELLE, L.M., PANKOW, J.F., & TRATNYEK, P.G. Method for Determination of Methyl *tert*-Butyl Ether and Its Degradation Products in Water. *Environ. Sci. Technol.*, 31:12:3723 (1997).